Constraining the evolution of the fundamental constants with a solid-state optical frequency reference based on the ^{229}Th nucleus

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The technological impact of atomic clocks has been profound, ranging from the successful implementation of global positioning systems and cellular telephones to the synchronization of modern-day electrical power grids. Improved clocks, based on optical frequency standards, are likely to have real-world utility at an even greater level. Furthermore, high- precision clocks have provided a means to probe fundamental issues in physics. For example, atomic clock experiments have provided some of the most stringent tests of General Relativity [1] and the variability of the fundamental constants [2]. Because of these motivations, there is presently enormous effort towards building next-generation atomic clocks. It appears universally recognized that the most promising route to improved clocks uses reference oscillators based on optical transitions. Indeed, several optical atomic clock experiments have already reported better stability than the primary U.S. Cesium standard [2,3].

We have recently described a novel optical frequency standard based on a high-Q transition in the ^{229}Th nucleus [4]. This "nuclear" clock architecture promises up to six orders of magnitude improvement in both the clock precision and the constraints on the variability of several fundamental constants, while simultaneously reducing experimental complexity. This paradigm shift in optical frequency standards is possible because, as indicated by recent data [5], the ^{229}Th transition has the lowest energy of any known nuclear excitation, making it amenable to study by laser spectroscopy. Furthermore, because nuclear energy levels are relatively insensitive to their environment, the complicated vacuum apparatus of current optical frequency standards can be replaced by a single crystal doped with ^{229}Th atoms.

This work, which draws heavily on both atomic and solid-state physics, has the possibility to open a new field of research, solid-state optical clocks, while simultaneously addressing the needs to establish both better physical standards and test the basic laws of physics. In this talk, we will discuss the effect of the solid-state environment on the nuclear transition, detail our plan to make the first precision measurement of the ^{229}Th nuclear transition, and comment on the applicability of this technique for constructing a solid-state optical frequency reference as well as constraining the variability of several important fundamental constants.

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3. A.D. Ludlow et al., Science 319, 1805 (2008).
4. W.G. Rellergert et al., Phys. Rev. Lett. (in press) (2010); arXiv:0905.2230
5. B.R. Beck et al., Phys. Rev. Lett. 98, 142501 (2007).